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(54) **UNIVERSAL CLAMPING CIRCUIT FOR
AUTOMOTIVE SWITCH GATE DRIVES**

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H02M 1/00 (2006.01)

H02M 1/34 (2007.01)

(52) **U.S. Cl.**

CPC **H03K 17/0822** (2013.01); **H02M 1/34**
(2013.01); **H03K 17/567** (2013.01); **H02M**
1/0048 (2021.05); **H02M 1/344** (2021.05)

(58) **Field of Classification Search**

CPC ... **H03K 17/0822**; **H03K 17/567**; **H02M 1/34**;
H02M 1/0048; **H02M 1/344**

See application file for complete search history.

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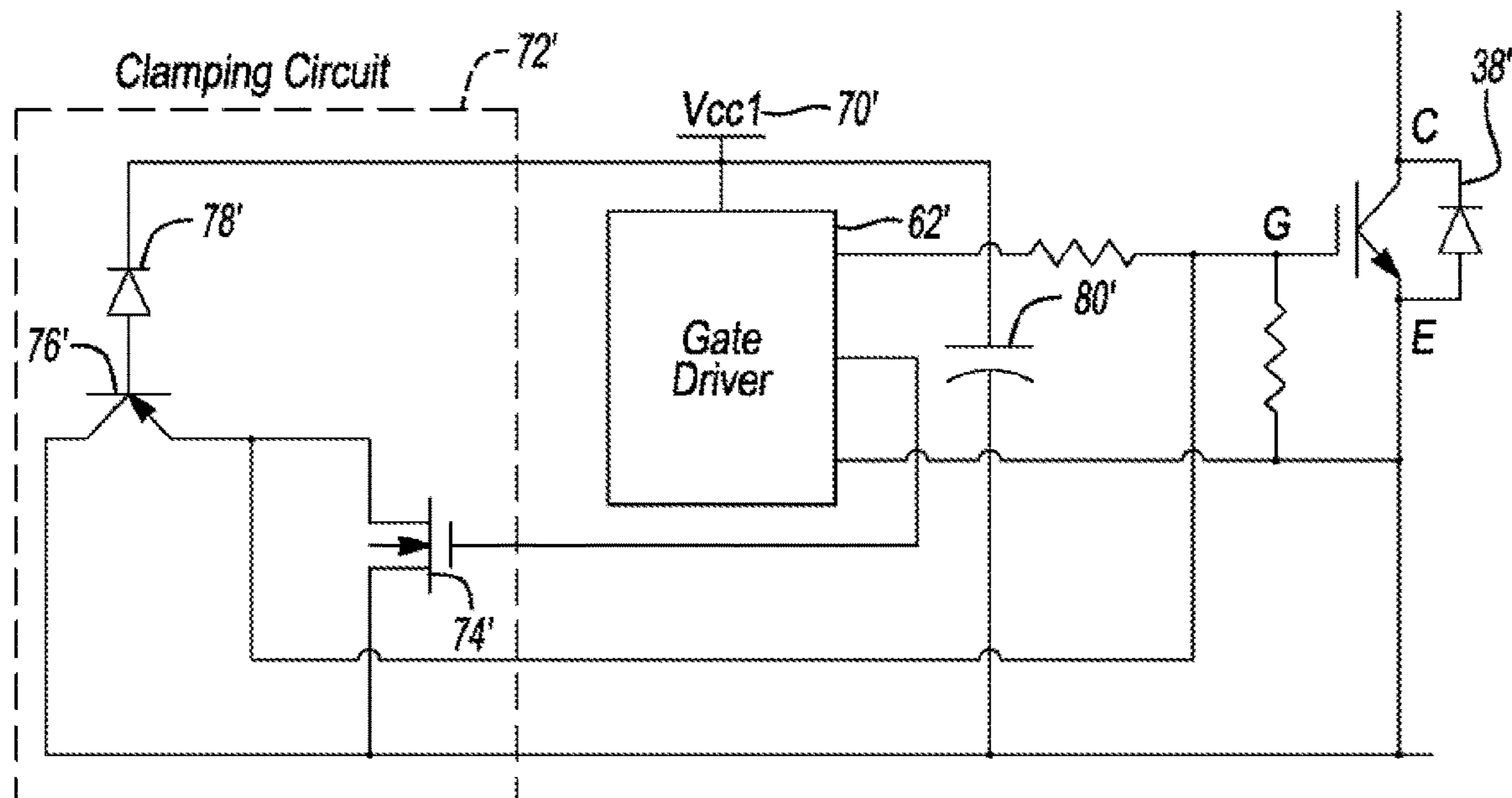
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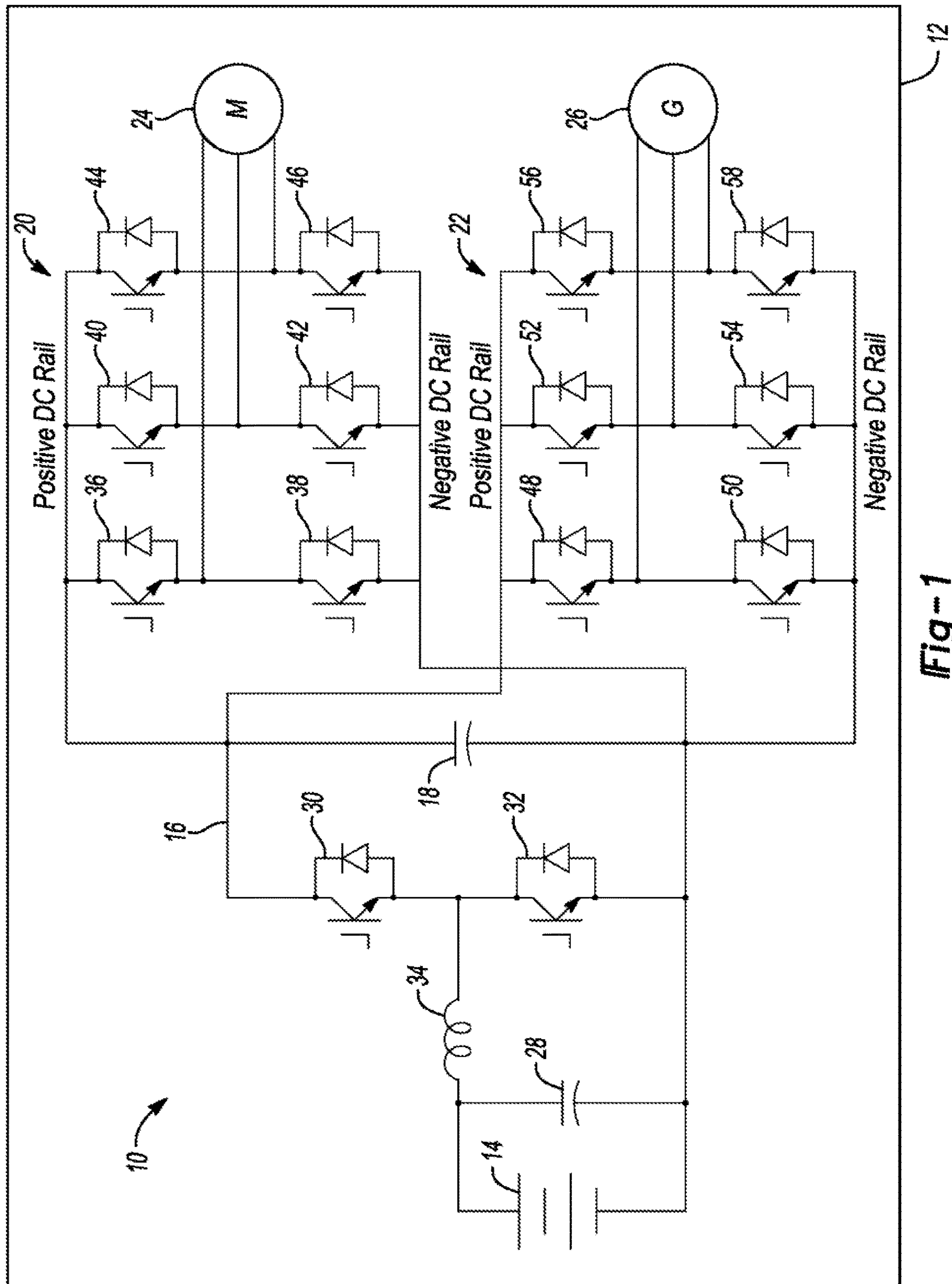
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(57) **ABSTRACT**

An automotive vehicle includes an electric machine, a
traction battery, and a power converter. The power converter
transfers power between the electric machine and traction
battery. The power convert includes a switch that defines a
portion of a phase leg, a gate driver circuit that provides
provide power to a gate of the switch, and a clamping circuit.
The clamping circuit includes a clamping switch that,
responsive to the gate driver circuit being de-energized and
a voltage of the gate exceeding a predetermined threshold
value, conducts current from the gate to dissipate the voltage
and clamp the gate to an emitter of the switch.

12 Claims, 3 Drawing Sheets





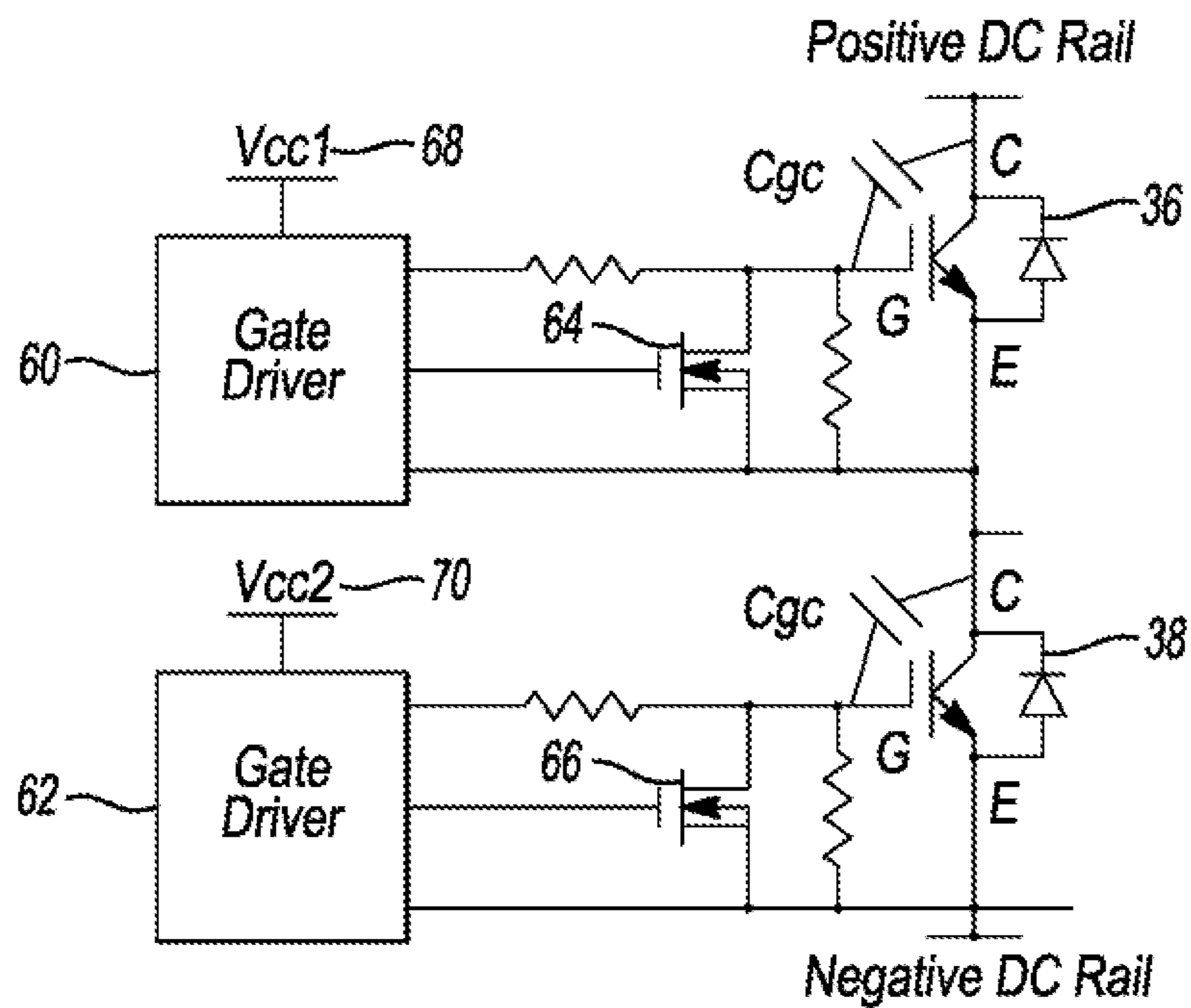


Fig-2

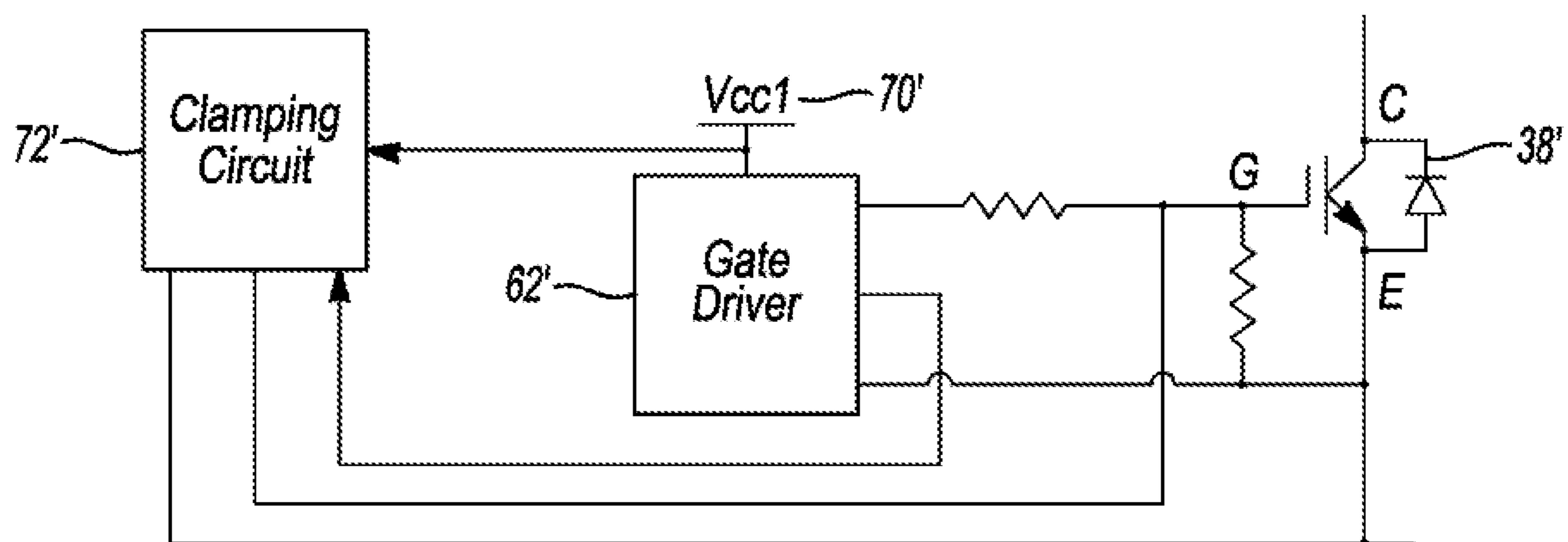


Fig-3

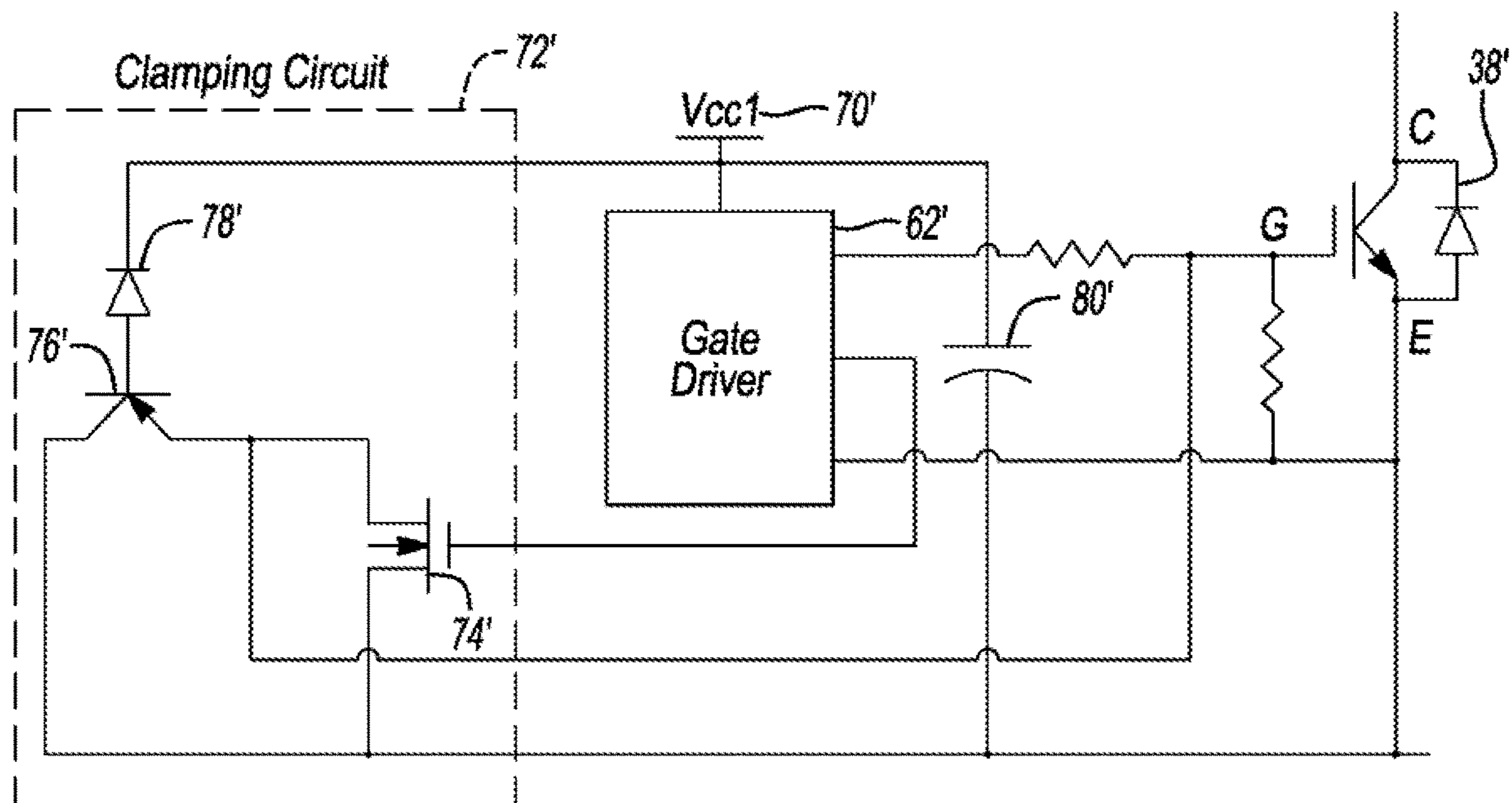


Fig-4

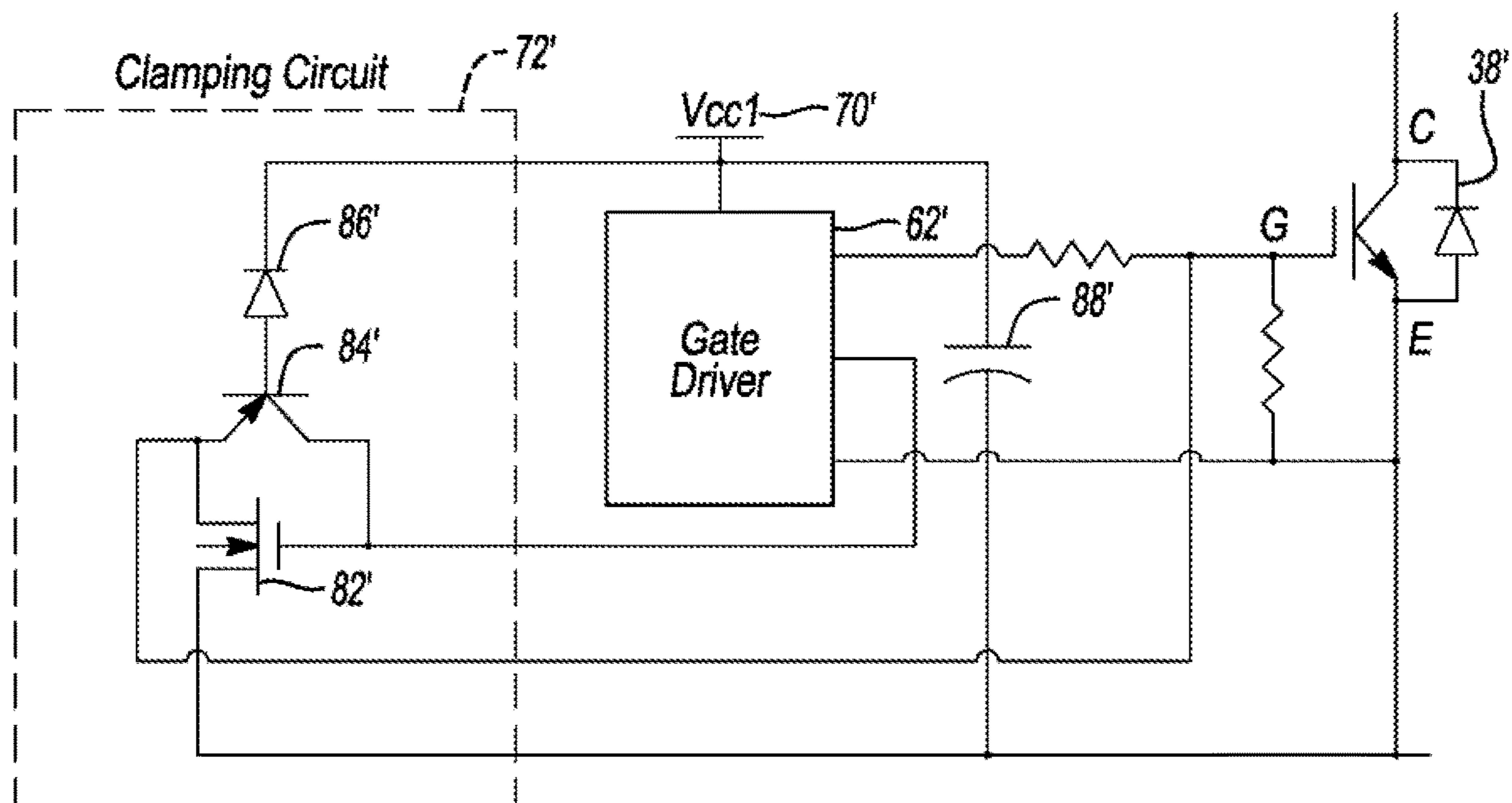


Fig-5

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UNIVERSAL CLAMPING CIRCUIT FOR
AUTOMOTIVE SWITCH GATE DRIVES

TECHNICAL FIELD

This disclosure relates to automotive power electronics components.

BACKGROUND

An electric or hybrid vehicle may contain one or more motors for propulsion. The vehicle may also contain a traction battery as a source of energy for the motor, and a generator to charge the traction battery. As the motor, traction battery, and generator may require varying electrical parameters, electrical communication between them may require modification of the power provided or consumed.

SUMMARY

An automotive vehicle includes an electric machine, a traction battery, and a power converter. The power converter transfers power between the electric machine and traction battery, and includes a switch defining a portion of a phase leg, a gate driver circuit that provides power to a gate of the switch, and a clamping circuit that includes a clamping switch. The clamping switch, responsive to the gate driver circuit being de-energized and a voltage of the gate exceeding a predetermined threshold value, conducts current from the gate to dissipate the voltage and clamp the gate to an emitter of the switch.

A power converter includes an insulated gate bipolar transistor (IGBT), a gate driver circuit that provides power to a gate of the IGBT, and a bipolar junction transistor (BJT). The BJT, responsive to the gate driver circuit being de-energized and a voltage of a gate of the IGBT exceeding a predetermined threshold value, conducts current from the gate to dissipate the voltage and clamps the gate to an emitter of the IGBT.

An automotive vehicle includes an electric machine, a traction battery, and a power converter. The power converter transfers power between the electric machine and traction battery, and includes a switch that defines a portion of a phase leg, a gate driver circuit that provides power to a gate of the switch, and a clamping circuit that includes first and second clamping switches. The first clamping switch, responsive to the gate driver circuit being de-energized and a voltage of the gate of the switch exceeding a predetermined threshold value, conducts current from the gate of the switch to a gate of the second clamping switch to increase a voltage of the gate of the second clamping switch. The second clamping switch, responsive to the voltage of the gate of the second clamping switch exceeding another predetermined threshold value, conducts current such that the gate and emitter of the switch are clamped together

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic diagram of an electric drive system off vehicle.

FIG. 2 is a schematic diagram of a phase leg of FIG. 1 and corresponding control circuitry.

FIG. 3 is a schematic diagram of proposed clamping circuitry.

FIG. 4 is a schematic diagram of an implementation of the proposed clamping circuitry of FIG. 3.

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FIG. 5 is a schematic diagram of another implementation of the proposed clamping circuitry of FIG. 3.

DETAILED DESCRIPTION

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Various embodiments of the present disclosure are described herein. However, the disclosed embodiments are merely exemplary and other embodiments may take various and alternative forms that are not explicitly illustrated or described. The figures are not necessarily to scale; some features may be exaggerated or minimized to show details of particular components. Therefore, specific structural and functional details disclosed herein are not to be interpreted as limiting, but merely as a representative basis for teaching one of ordinary skill in the art to variously employ the present invention. As those of ordinary skill in the art will understand, various features illustrated and described with reference to any one of the figures may be combined with features illustrated in one or more other figures to produce embodiments that are not explicitly illustrated or described. The combinations of features illustrated provide representative embodiments for typical applications. However, various combinations and modifications of the features consistent with the teachings of this disclosure may be desired for particular applications or implementations.

Power electronics converters/inverters have been extensively used in hybrid electric vehicle and electric vehicle drive systems. As shown in FIG. 1, an electric drive system 10 for a vehicle 12 includes a traction battery 14, a bridge-based DC-DC converter 16, a DC-link capacitor 18 for DC bus 19, two power converters (DC-AC inverters) 20, 22, a motor 24, and a generator 26. The bridge-based DC-DC converter 16 includes a capacitor 28 in parallel with the traction battery 14, a pair of series connected switches 30, 32 (e.g., transistors), and an inductor 34 between the capacitor and series connected switches 30, 32.

The DC-AC inverter 20 includes, in this example, three pairs of series connected switches 36, 38, 40, 42, 44, 46. Each of the pairs defines a corresponding phase leg for the motor 24. The DC-AC inverter 26 also includes three pairs of series connected switches 48, 50, 52, 54, 56, 58. Each of the pairs defines a corresponding phase leg for the motor generator 26. The switches 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58 can be insulated gate bipolar transistors (IGBTs), metal oxide semiconductor field effect transistors (MOSFETs), or other controllable semiconductor devices. In the following examples, the switches 36, 38, 40, 42, 44, 46, 48, 50, 52, 54, 56, 58 are shown to be IGBTs.

A voltage associated with power from the traction battery 14 may be increased by operation of the bridge-based DC-DC converter 16 for eventual delivery to the DC-AC inverter 20 and thus the motor 24 to propel the vehicle 12. Likewise, regenerative power captured by the generator 26 may be passed through the DC-AC inverter 22 and so on for storage in the traction battery 14.

Dual-on conditions can occur across the phase legs of the DC-AC inverters 20, 22. Gate signals of the switches 36, 38, for example, are usually complementary. In normal operating conditions, only one of the switches 36, 38 is turned on at any time. In the dual-on condition, the switches 36, 38 are on at the same time, and the high DC voltage source is directly short circuited by the low impedance formed by the on-state resistances of the switches 36, 38. The dual-on condition can generate a large current that is much higher than the normal operating current of the switches 36, 38.

FIG. 2 shows one of the phase legs of the DC-AC inverter 20 and its gate driver circuits 60, 62. The switches 36, 38 are

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the main power switches as implied above, and switches **64**, **66** are, in this example, miller-clamp switches. When the gate driver circuits **60**, **62** are energized by power supplies **68**, **70** respectively, the output status of the gate driver circuits **60**, **62** is either high or low. When the switches **36**, **38** are off, the clamping switches **64**, **66** are turned on, and the gate G to emitter E of each of the switches **36**, **38** is shorted by the low impedance of the switches **64**, **66** respectively. Therefore, the switches **36**, **38** are in the off state. Several resistors are also shown in FIG. 2 and other figures. These are arranged in usual fashion and therefore need not be discussed in further detail.

When the power supplies **68**, **70** have no power however, the gate driver circuits **60**, **62** and miller-clamping switches **64**, **66** lose function. The outputs of the gate driver circuits **60**, **62** are in a high-impedance state, and the miller-clamping switches **64**, **66** are also in a high-impedance state. Therefore, the gate-to-emitter impedance of each of the switches **36**, **38** is very high. If high voltage is applied to the DC bus **19** in this situation and the DC bus voltage fluctuates, current flowing through the parasitic capacitor Cgc of each of the switches **36**, **38** will charge the gate capacitor of each of the switches **36**, **38**. If the DC bus voltage changes fast enough, the generated gate voltage by the charge current flowing through Cgc will cause the switches **36**, **38** to turn on. If both of the switches **36**, **38** are turned on, then a dual-on condition will occur as explained above.

Here, clamping circuits are proposed that prevent unintentional switch activation conditions of converters/inverters regardless of whether gate driver power supplies are energized.

As shown in FIG. 3, clamping circuit **72'** monitors the power supply **70'**, if the power supply **70'** is not energized, the clamping circuit **72'** shorts the gate G to the emitter E of the switch **38'** by a low impedance to prevent the switch **38'** from turning on. If the power supply **70'** is energized, the clamping circuit **72'** cooperates with the gate driver circuit **62'** to prevent the switch **38'** from inadvertently turning on. Such circuitry, for example, could be associated with each of the switches **38**, **42**, **46** (FIG. 1) and the switches **50**, **54**, **58** (FIG. 1).

One implementation of the proposed clamping circuit **72'** is shown in FIG. 4. The clamping circuit **72'** includes switches **74'**, **76'**, diode **78'**, and capacitor **80'**. In this example, the switch **74'** is a metal oxide semiconductor field effect transistor (MOSFET) and the switch **76'** (clamping switch) is a bipolar junction transistor (BJT). They can be discrete devices or integrated into the gate driver integrated circuitry. Other types of switches/transistors may also be used. The gate of the MOSFET **74'** is directly electrically connected with an output of the gate driver **62'**. And the drain and source of the MOSFET **74'** are electrically connected between the emitter of the BJT **76'** and the emitter of the IGBT **38'**, with the drain being directly electrically connected with the emitter of the BJT **76'** and the source being directly electrically connected with the emitter of the IGBT **38'**. The base of the BJT **76'** is directly electrically connected with the anode of the diode **78'**. The emitter of the BJT **76'** is directly electrically connected with the gate of the IGBT **38'**. And the collector of the BJT **76'** is directly electrically connected with the emitter of the IGBT **38'**. One terminal of the capacitor **80'** is directly electrically connected to the power supply **70'** and the cathode of the diode **78'**. The other terminal of the capacitor **80'** is directly electrically connected to the emitter of the IGBT **38'**.

Responsive to the power supply **70'** not being applied, the switch **76'** performs the clamping function. Once the gate

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voltage of the switch **38'** exceeds the threshold voltage of the switch **76'** (e.g., 1.4V), the switch **76'** will complete the circuit between the gate and emitter of the switch **38'**, conduct to discharge the parasitic capacitance Cge of the switch **38'**, and clamp the gate voltage of the switch **38'** to be under 1.4V, which is lower than the turn-on threshold voltage of the switch **38'**. Therefore, the switch **38'** can be in the off state. Responsive to the power supply **70'** being applied, the switch **76'** will be in the off state, and the switch **74'** will perform the clamping function as described with reference to the switch **66** of FIG. 2.

Another implementation of the proposed clamping circuit **72'** is shown in FIG. 5. The clamping circuit **72'** includes switches **82'**, **84'**, diode **86'**, and capacitor **88'**. In this example, the switch **82'** is a MOSFET and the switch **84'** (clamping switch) is a BJT. Other arrangements, however, are also possible. The gate of the MOSFET **82'** is directly electrically connected with the collector of the BJT **84'** and an output of the gate driver **62'**. And the drain and source of the MOSFET **82'** are electrically connected between the emitter of the BJT **84'** and the emitter of the IGBT **38'**, with the drain being directly electrically connected with the emitter of the BJT **76'** and the source being directly electrically connected with the emitter of the IGBT **38'**. The base of the BJT **84'** is directly electrically connected with the anode of the diode **86'**. One terminal of the capacitor **88'** is directly electrically connected to the power supply **70'** and the cathode of the diode **86'**. The other terminal of the capacitor **88'** is directly electrically connected to the emitter of the IGBT **38'**.

Responsive to the power supply **70'** not being applied, the switches **82'**, **84'** perform the clamping function. Once the gate voltage of the switch **38'** exceeds the threshold voltage of the switch **84'** (e.g., 1.4V), the switch **84'** will conduct to charge the gate of the switch **82'**. As the gate voltage of the switch **82'** exceeds the turn-on threshold of the switch **82'**, it will conduct and discharge the parasitic capacitance Cge of the switch **38'** together with the switch **84'**. The gate voltage of the switch **38'** will be clamped to 1.4V. Responsive to the power supply **70'** being applied, the switch **84'** will be in the off state, and the switch **82'** will perform the clamping function as described with reference to the switch **66** of FIG. 2.

The processes, methods, or algorithms disclosed herein may be deliverable to or implemented by a processing device, controller, or computer, which may include any existing programmable electronic control unit or dedicated electronic control unit. Similarly, the processes, methods, or algorithms may be stored as data and instructions executable by a controller or computer in many forms including, but not limited to, information permanently stored on non-writable storage media such as ROM devices and information alterably stored on writeable storage media such as floppy disks, magnetic tapes, CDs, RAM devices, and other magnetic and optical media. The processes, methods, or algorithms may also be implemented in a software executable object. Alternatively, the processes, methods, or algorithms may be embodied in whole or in part using suitable hardware components, such as Application Specific Integrated Circuits (ASICs), Programmable Gate Arrays (FPGAs), state machines, controllers or other hardware components or devices, or a combination of hardware, software and firmware components.

The words used in the specification are words of description rather than limitation, and it is understood that various changes may be made without departing from the spirit and scope of the disclosure and claims. As previously described,

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the features of various embodiments may be combined to form further embodiments that may not be explicitly described or illustrated. While various embodiments may have been described as providing advantages or being preferred over other embodiments or prior art implementations with respect to one or more desired characteristics, those of ordinary skill in the art recognize that one or more features or characteristics may be compromised to achieve desired overall system attributes, which depend on the specific application and implementation. These attributes include, but are not limited to cost, strength, durability, life cycle cost, marketability, appearance, packaging, size, serviceability, weight, manufacturability, ease of assembly, etc. As such, embodiments described as less desirable than other embodiments or prior art implementations with respect to one or more characteristics are not outside the scope of the disclosure and may be desirable for particular applications.

What is claimed is:

1. An automotive vehicle comprising:
an electric machine;
a traction battery; and
a power converter configured to transfer power between the electric machine and traction battery, and including a switch defining a portion of a phase leg, a gate driver circuit configured to provide power to a gate of the switch, and a clamping circuit including a clamping switch, wherein the clamping switch is configured to, responsive to the gate driver circuit being de-energized and a voltage of the gate exceeding a predetermined threshold value, conduct current from the gate to dissipate the voltage and clamp the gate to an emitter of the switch, and wherein the clamping circuit further includes a metal oxide semiconductor field effect transistor having a gate directly electrically connected with the gate driver circuit.
2. The vehicle of claim 1, wherein the clamping switch is a bipolar junction transistor (BJT), and wherein a collector of the BJT is directly electrically connected with the emitter of the switch.
3. The vehicle of claim 1 further comprising a diode electrically connected between the clamping switch and the gate driver circuit, wherein the clamping switch is a bipolar junction transistor (BJT), and wherein a base of the BJT is directly electrically connected with an anode of the diode.
4. The vehicle of claim 1, wherein the metal oxide semiconductor field effect transistor further has a drain and source electrically connected between the clamping switch and the switch.
5. The vehicle of claim 1, wherein the switch is an insulated gate bipolar transistor.

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6. A power converter comprising:
an insulated gate bipolar transistor (IGBT);
a gate driver circuit configured to provide power to a gate of the IGBT; and
a bipolar junction transistor (BJT) configured to, responsive to the gate driver circuit being de-energized and a voltage of a gate of the IGBT exceeding a predetermined threshold value, conduct current from the gate to dissipate the voltage and clamp the gate to an emitter of the IGBT, wherein a collector of the BJT is directly electrically connected with the emitter of the IGBT.
7. The power converter of claim 6 further comprising a diode electrically connected between the BJT and the gate driver circuit, and wherein a base of the BJT is directly electrically connected with an anode of the diode.
8. The power converter of claim 7, wherein the clamping circuit further includes a metal oxide semiconductor field effect transistor (MOSFET) having a gate directly electrically connected with the gate driver circuit.
9. The power converter of claim 8, wherein a drain and source of the MOSFET are electrically connected between the BJT and the IGBT.
10. An automotive vehicle comprising:
an electric machine;
a traction battery; and
a power converter configured to transfer power between the electric machine and traction battery, and including a switch defining a portion of a phase leg, a gate driver circuit configured to provide power to a gate of the switch, and a clamping circuit including first and second clamping switches,
wherein the first clamping switch is configured to, responsive to the gate driver circuit being de-energized and a voltage of the gate of the switch exceeding a predetermined threshold value, conduct current from the gate of the switch to a gate of the second clamping switch to increase a voltage of the gate of the second clamping switch, and
wherein the second clamping switch is configured to, responsive to the voltage of the gate of the second clamping switch exceeding another predetermined threshold value, conduct current such that the gate and emitter of the switch are clamped together.
11. The automotive vehicle of claim 10, wherein the gate of the second clamping switch is directly electrically connected with the gate driver circuit.
12. The automotive vehicle of claim 10, wherein the first clamping switch is a bipolar junction transistor and the second clamping switch is a metal oxide semiconductor field effect transistor.

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